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STATUS OF GROUND CONTAMINATION PROBLEM

1. Introduction

Since January 1954 there have been several emissions of radio-ruthenium particulates from the Redox stack that have collectively established a ground contamination pattern more severe than any that has been observed at this site in previous years. Informal status reports on this topic have been submitted to you from time to time. The purpose of this report is to bring such reports up-to-date, and particularly to outline the current situation as it affects off-project locations.

2. Sequence of Contaminating Events

The history up to July, 1954 has been documented. (Ref: D.P. Ebright to W. A. McAdams "A History of the Redox Ruthenium Problem" - HW-32473. 7-16-54)

There follows a brief review of the salient features in note form.

(1)	March 8, 1952	failure of caustic scrubber. local contamination
(2)	April 3, 1952	highly active particle (40 rads/hr) found on survey instrument
(3)	April 29, 1952	widespread contamination in Redox areas readings up to 800 mrads/hr. program of examining deposition on glass fiber mats began
(4)	June 24, 1952	large flaky particles of ammonium nitrate carrying Ru contamination
(5)	September 1952	30-fold increase in particle deposition
(6)	August 14, 1953	large fragments of ammonium nitrate. up to several inches length and width and 3/4 inch thick. curvature compatible with origin in stack liner. dose rates up to 15 rads/hr
(7)	Sept. 5,6, 1953	approximately 115 curies of ruthenium released. no specific deposition problem reported.
(8)	Jan. 2, 1954	approximately 260 curies released. narrow band of contamination northeast, detectable as far as Spokane. general ground contamination up to 7.5 rads/hr in vicinity of Redox plant. Access controls applied.

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(9) Jan. 5, 1954 approximately 70 curies. possibly caused by stack flushing. contamination local to Redox area

(10) April 24, 1954 small contaminated area found one mile from Redox plant. emission date not known. transfer by wind action unlikely because main ground deposition at this time appeared to maintain position

(11) May 22, 1954 strip of contamination north through 100-B Area and on to Wahluke Slope

(12) May 24, 1954 similar strip east through construction areas in 200-E. construction halted and 300 acres of affected ground cleaned

(13) June 10 - July 18, 1954 Redox plant shut down. improvements to stack air system made

(14) June 20, 1954 contamination detected outside perimeter barricade in direction of Richland. Richland itself essentially clean

(15) June 28, 1954 ten-fold increase in activity levels on control plots established around Redox plant in January. believed due to release of old material from stack itself

(16) August, 1954 plan developed to control access to areas off roads in about one-half of the reservation (Refs.: 1 - Letter, H.M. Parker to D.F. Shaw - Control of Ground Contamination HW-32808. 8-19-54.
2 - Advice to Management Information Group - Control of Ground Contamination - 8-20-54)

(17) late August, 1954 contamination spread off-site.
Examples: Richland - approx. 1 particle per 1000 sq. ft. on grassy areas, 1 per 3000 sq. ft. on bare areas. maximum dose-rate about 180 mrads/hr.
contamination at Ringold, Mesa, Benton City, Enterprise - max. 700 mrads/hr. Contamination probable but not yet measured in all other local communities.
This spread is presumed due to wind action.

(18) August 30,1954 current status again reported verbally to AEC by W. E. Johnson and H. M. Parker. Commission proposal is to control whole of reservation. Dr. Bugher, Div. of Biology and Medicine will be asked to visit the site for consultation.

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3. Comments on Deposition

Some of the listed events were caused by large emissions recorded by stack monitors. Others clearly occurred at times when stack monitor readings were normal. Almost beyond question, these were due to release of coating material from the stack liner.

The evidence on subsequent motion of once deposited particles is conflicting. The heavy pattern laid down in early January was generally maintained, although individual particles were found to be mobile. The recent shift in late August was almost certainly due to wind action.

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A plausible explanation is that true primary emissions occur as small particles that attach themselves to vegetation or sand. Subsequent mobility will be determined by mobility of the host. Secondary emissions as larger particles may be more freely mobile in the wind, once they are on the ground.

As a graphic illustration of the severity of the current deposition at off-reservation locations, one can picture the entire population of Richland lying unclothed on the ground for one day. There would be about 25 identifiable particles in contact with skin; not more than three would be in an activity type range that could produce a significant effect; not more than one would probably produce an effect.

4. Nature of Particles

The primary small particles are presumably composed principally of ruthenium oxide RuO_2. Typical dimensions are on the order of 2 microns. The maximum activity of such a particle is 5 x 10-3 μc. Its survey dose-rate would be approximately 0.5 mrad/hr. The particles of main current concern are large, typically about 100 microns across, with dose-rates up to 20 rads/hr and activities up to about 200 μc. These must be some form of aggregate on a carrier base, which is sometimes ammonium nitrate and sometimes sand. Complete categorization of particle types is laborious and is not being pressed at this time. On the whole, the particles are about one part active ruthenium oxide to 40 parts inert carrier. The contaminants in the particles are predominantly Ru^{103} and Ru^{106} and their respective daughters Rh^{103} and Rh^{106}. The daughters have short half-lives. Therefore, the ruthenium parents control the rate of decay.

The radiochemistry of individual particles undoubtedly varies. Typically, the content of dangerous isotopes other than ruthenium is:

Strontium-89 and Strontium-90	$<$ 0.3%
Rare earths plus yttrium	$<$1.0%
Zirconium^{95}	$<$0.5%

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The ruthenium content is on the order of 98%, although this has not been demonstrated by precise radiochemical balance.

Particles collected on the input side of the process sand filter have a demonstrably different composition, since this stream collects fission product activity from steps in which ruthenium is not being specifically separated. These particles typically contain about 80% ruthenium-103 and 106, 10 - 15% rare earths and 1 - 2% strontium-89 and 90.

The calculations in this review are based on the typical emitted particles with all the activity considered to be due to ruthenium.

5. Life of the Particles and Persistence of the Problem

The relevant half lives are Ru^{103} - 40 days
Ru^{106} - 1 year

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The isotopic ratio Ru^{103}/Ru^{106} is a function of the time after reactor irradiation, and can therefore be used as a measure of the age of particles.

Current process material has an isotopic ratio of 2 to 4. Many of the particles on the ground originally showed ratios in the range of 0.4 to 1.0. This is compatible with a hold-up in the stack of between two and four months.

Since the start-up of the Redox plant in July, emitted particles have shown the low isotopic ratio of 0.8 to 1.0. Presumably, the emissions are now principally purges of previously held-up material.

New particles will have a mixed decay rate characterized by:

First half life	2 months
Second half life	3 months
Third half life	7 months
Subsequent half lives	approximately 1 year

The contamination problem for new particles should be down to 12% of its original intensity in one year, and will thereafter show a one year half-life. For the existing pattern of contamination, the intensity of the problem should be down to 20% of its present value in one year, and will thereafter show a half life of one year. Unfortunately, the hazard is governed more by Ru^{106} than by Ru^{103}. The true persistence will be greater than is indicated by total decay, and may approximate a half-life of one year throughout.

Persistence may be reduced by some dissolution of the particles by rain and by cover by naturally blown sand and dust. We are unable to evaluate these factors at present.

6. Solubility of Particles

The particles, normally classed as relatively insoluble, in fact show variable and fairly high ultimate solubility. Particles in the inhalable range were tested in serum to simulate lung conditions. Solubility in 36 hours ranged between 40% and 80%, depending on the size fraction used, with an over-all average of 70%.

Large particles (several hundred microns diameter) were tested for ingestion hazard by solution in simulated gastric juice. Solubility in 48 hours, approximately the maximum travel time through the gastro-intestinal tract, varied from 3% to 70%. Such variability is presumably related to the different methods of binding of active material and inert carrier in the large particles.

The solubility in rain water has not been directly measured. The persistence of contamination patterns through a rainstorm of 0.4 inch is enough to demonstrate that solubility is not spectacular. Conversely, around roof drains there is evidence of generalized activity probably by solution of material on roofs, though possibly due to a multitude of very small particles washed down as such.

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7. Biological Experiments

Uptake of ruthenium in the gut of rats was measured for particle and solution contamination; uptake from solution was 100-fold greater. However, local experiments show uptake also 100-fold greater than the values quoted in NCRP Handbook 52. Provisionally, permissible dose for ingestion can be reasonably computed directly from the handbook, as the two factors would compensate.

Lung exposures are in process, but there are no results to date. In one human case, clearance of ruthenium activity from the lung had a biological half-life of two to three weeks.

Large particles were applied to the skin of pigs for five to seven days. Results were:

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Survey Dose Rate mrads/hr	Total Skin Dose rads	Effect
400	~ 500,000	none visible
750	~ 900,000	reddening
2,500	~ 2,000,000	desquamation
11,000	~ 6,000,000	tissue destruction
21,000	~ 7,000,000	tissue, destruction 2 cm across; 8 mm deep

Total dose refers to the hot spot directly below the particle, and is valid only as to order of magnitude.

Qualitatively, damage does not set in at as low a dose as anticipated, but at very high dose, it is perhaps more extensive than was anticipated.

Pig skin and human skin are sufficiently alike that if the pig can wear a 400 mrad/hr particle for five days, I would be willing to wear one for one day.

Numerous researches are in progress to determine the effect of ruthenium solutions on plants etc. to provide data on hazards from dissolved particles.

8. Contamination of Vehicles and Personnel

The pick-up of particles on vehicles and the subsequent risk of such particles creating a secondary hazard has been studied fairly extensively (Ref: H.V. Clukey et al Emergency Study - Hanford Vehicle Contamination HW-31800 5/21/54) The hazard from this source is not expected to be large.

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A striking feature of the contamination has been the low incidence of demonstrable contamination of personnel doing monitoring or other work in areas infested by particles. About three such cases have been reported in which a particle has contrived to lodge behind a belt or find a similar protected place. In general, the particles must be rather readily dislodged from their position on skin or clothing.

9. Crop and Livestock Contamination

Ground contamination was found in orchards and field crop areas. Crops tested include 2500 peaches, 2 lugs of plums, 2 lugs of grapes, 1500 apples, 40 ears of corn and 40 tomatoes. No particulate contamination whatsoever was detected. Crops from affected areas have been allowed to proceed to market.

We have considered the hazard to cattle and other livestock. On the Wahluke Slope, cattle droppings are demonstrably contaminated. However, the available contamination should not present an appreciable direct hazard to livestock. As a secondary hazard to man, one need consider only kidney and liver. We were interested in obtaining such organs from local stock, but could not do it without risk of exciting too much comment. As kidney and liver are a low percentage of the normal diet, it seems safe to assume that the hazard to man would be insignificant.

10. Note on Dosimetry

All field data on the particles are reported in mrads per hour as monitored under standard conditions. Calculation and measurement of the true contact dose rates are in approximate agreement. Typical values are given in Appendix A. Briefly here a particle reading 100 mrads per hour has a diameter of approximately 40 μ and contains 1.1 μc $Ru^{103,106}$ and a particle reading 1 rad per hour has a diameter approximately 120 μ and contains 11 μc.

The 100 mrad per hour particle in skin contact for 24 hours delivers approximately 160,000 rads at the contact point. Delivered over a large area such a dose would be devastating. Over the minute area involved here, the effective exposure is much less.

e.g. 160,000 rads at contact
16,000 rads at 0.22 mm radius
1,600 rads at 0.56 mm radius
160 rads at 1.7 mm radius
16 rads at 5.0 mm radius

Over a 1 cm diameter circle, the dose varies by 4 orders of magnitude. My best guess at the effective dose (and it is little more than a guess) is that it would be comparable with 200 to 2000 rads over an extended area. If the low value is about right, there would be no visible effect. If the high value is about right, there would be tanning, persistent erythema and perhaps some degree of desquamation.

By comparison with the statements in Section 7, it may perhaps be inferred that I really anticipate that a 400 mrad per hour particle for one day would not produce more damage than severe erythema or desquamation on human skin - that is an extended dose of about 1200 rads. In other words, I suspect that the nominal effective range, above, of 200-2000 rads centers around approximately 300 rads.

This point can be answered only by human experimentation. This appears to be an entirely safe procedure, and four volunteers are available. As an added precaution, the opinion of selected persons familiar with beta-ray exposures is being solicited first.

11. Biological Hazards in Richland and Vicinity

a. External Radiation

Particles of the activity found in Richland and other neighboring communities can give skin contact doses well above conventional safe limits. However, as shown above, it can reasonably be expected that actual injury to any individual will be either absent altogether or limited to reddening over an area of less than 1 cm^2. At the worst, there would be a small necrotic area, perhaps comparable with the effect of plunging a lighted match head on to the skin. My best guess is that this would not happen in one day's contact with the hottest known off-site particle.

b. Inhalation

Inhalation into the lung is essentially limited to particles under 5 μ diameter. The hottest possible particle of this size, without carrier, would contain 0.08 μc Ru. The typical small particle would contain not more than 0.01 μc. In the 2 μ range, more probable for inhalation, the maximum activity is 5×10^{-3} μc. The permissible inhalation load of Ru^{106} is 0.6 μc/day. The apparent hazard of lung deposition, off-site, is therefore low.

Some larger particles could be retained temporarily in the upper respiratory tract. These would characteristically be moved by ciliary processes, and the chance of significant irradiation is low. (See Appendix B)

The lung deposition limit is predicated on soluble material. The hazard from that portion that may be effectively insoluble is difficult to evaluate. Calculation would show the possibility of highly localized exposures up to 60 rads/hr. I believe that most experts would not be alarmed by the particulate inhalation risk at these levels.

c. Ingestion

The permissible daily ingestion is about 200 μc/day. With ground deposits not in excess of 0.5 μc per 1000 sq. ft. and the maximum single particle activity (off-site) of approximately 15 µc, this hazard even to children playing, is remote. Similarly, crop or fruit contamination would have to be very severe before restrictions were needed.

However, the quoted limit is based on assumed uniform dispersion of the material in food or water. As particulates, one could visualize a situation in which some local-irradiation of gut lining occurred, and if this led to puncture of the gut wall, the situation would be unfavorable. I do not believe that this is possible, but others with better knowledge of human physiology could offer more definitive opinions on this point. (See Appendix C)

In summary, although there are definite areas of uncertainty in the biological evaluation, it is my opinion that the severity of injury of any person at off-site locations under the present conditions of measurement would be minimal; in addition, the probability of contact with active particles under disadvantageous conditions is low. Multiplying these factors of minimal severity and low probability of occurrence, the total risk is believed to be low.

12. Biological Hazards on the Reservation

a. External Radiation

The available particles on site are more copious by a factor of at least 100, and the maximum activity is as much as 30 times greater. Recognizable severe skin damage is possible and the chance of its occurrence quite finite.

Control is being maintained by regulating access to the worst areas. Currently, there are demonstrable weaknesses in the control program, especially as applied to such organizations as the military forces. Controls are being strengthened as rapidly as possible.

An encouraging feature is the absence of demonstrable injury to date. Indirectly, this supports our belief that no damage will occur off-site.

b. Inhalation

The maximum severity is the same as it is off-site. The probability of particle inhalation is much greater. One positive case is known. Lung content was 0.25 µc, whhch is below the permissible daily intake.

c. Ingestion

Potential risk is increased, but this is not visualized as the leading hazard. Appendix C applies for the gut irradiation. Sufficient intake to make a damaging body deposition calls for ingestion of one of the most active known particles per day or 10 of the normal selection of very hot particles (coded red on our reference maps).

13. Feasible Protective Measures

On-site control will be obtained by restriction of traffic to main roads and monitoring of areas, where secondary road travel is needed by work crews. Close cooperation with the AEC on these control proposals has been maintained. (Refs.: (1) HM Parker to DF Shaw. Control of Ground Contamination HW-32808 8-19/54. (2) Rough draft reply (to be documented later) DF Shaw to WE Johnson 8-31-54. (3) Preliminary Advice to management group - Control of Ground Contamination 8-20-54)

Present status is that control methods and appropriate signs have been agreed upon; signs will be made as rapidly as possible. (estimate - 2-3 weeks)

Off-site, the cost of complete removal of particles is prohibitive. Partial clean-up would be feasible if one could be convinced that particles below a certain level (e.g. 100 mrads per hour) could be ignored.

Clean-Up Work Load - Richland

Detection Limit (mrads per hour)	Method	Man-Hours
2	by hand	100,000
20	by hand	50,000
100	motorized equipment	5,000

The most promising approach is to apply techniques used in defense against wind erosion of soil, namely to plow or dig irregular trenches in the heavily infested areas on site. These should preferentially catch particles moved by the wind. This is being tested experimentally.

Other simplifying techniques being considered include the heavy sprinkling of bad areas with innocuous fluorescent particles to serve as monitoring tracers.

For direct protection of personnel, normal personal hygiene would seem to provide adequate protection. This supports our feeling that nothing is to be gained by informing the public of a risk that, off-site, is probably non-existent. The best protection is already being utilized.

14. Prevention of Recurrence

Process modifications are in the hands of the Engineering Department and Manufacturing Department and they will be adequately documented elsewhere. This phase of the work has been energetically pushed throughout the current year. All recommendations of this department have been fully considered and appropriate action taken. Since the major modifications were made during the shutdown of June - July 1954, there has been no evidence of significant particle escape through the system. However, the responsible organizations are not yet completely assured of the adequacy of the preventive measures.

Elimination of the head-end treatment and substitution of a tail end treatment is a reserve defense measure that is being carefully studied.

The stack monitor system has undergone substantial changes in the same period. The Manufacturing Department operates a strip filter at the 20-foot stack level and will soon have similar systems at the inlet and outlet of the sand filter.

The Radiological Sciences Department operates filter-scrubber combinations at the 20-foot and 190-foot stack levels. These are reliable systems with one exception. Sampling should be done under iso-kinetic conditions; this is not possible at present when the upper sampler can be presented with all sizes of particles from the sub-micron range to the one inch pieces from the stack lining. Those emissions that lead to large particle deposition (and apparently to the major hazard) may be missed. Development in this field is being attempted.

15. Information to the AEC

As the current situation has developed, the Commission has been kept fully informed by verbal contacts and exhibitions of colored maps, which are more effective than written reports. We have the Commission's verbal approval that this method of communication adequately discharges our contractual obligations in the matter. If and when the condition stabilizes it would seem appropriate to submit a formal analysis. A copy of this report would also provide a general summary for the Commission's use.

Before the close of this week, one copy of the current maps of deposition in color will be submitted to the AEC.

Also through AEC cooperation, Dr. J. C. Bugher, Director, Division of Biology and Medicine, AEC, Washington will visit Richland to review the problem.

The legal aspects of the problem have been discussed with George C. Butler.

16. Information to the Public

It seems to be agreed that if a demonstrable hazard to the public exists, appropriate releases should be made officially by the AEC, and in effect jointly by the Commission and the Company. As an intermediate step it may be determined that state pollution officials should be advised. We have previously had excellent cooperation from this source in matters of Columbia River contamination. This point will be decided during Dr. Bugher's visit. We are wholeheartedly in favor of such a communication.

There is a definite probability that information, or rather misinformation, on the off-site condition will leak to the public in the near future. Not all the residents will be as relaxed as the one who was recently quoted as saying, "Living in Richland is ideal because we breathe only tested air." To prepare for adverse questions, a suitable press release is being developed to be held in readiness.

17. Notes Added after Consultation with Dr. J. C. Bugher

On September 10 and 11, 1954, the above report and the general particle contamination problem were discussed with Dr. J. C. Bugher and Dr. R. Albers, Washington Atomic Energy Commission. This section will document the principal areas of disagreement or modification of emphasis between the consultants and ourselves.

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a. External Radiation

Referring to Section 11, we have limited the discussion on skin reactions to the acute stage, including the possible inflammatory processes. No major concern was expressed by the consultants in this area. Our proposal to make human skin tests was strongly endorsed. In fact, the consultants recommended carrying the tests to more severe reactions than we had planned to develop.

On the adverse side, the consultants were quite concerned about the possible development of late malignant changes in irradiated skin. One has to concede that this contingency is possible; to make a realistic appraisal of its probability is difficult.

We have roughly examined the case under three popular hypotheses of carcinogenesis in skin. On the basis of somatic mutation, the hazard can be completely dismissed, being substantially less than that involved in the conventional permissible weekly dose. On the basis of subsequent aberrent growth of cells once irradiated to damaging levels (several thousand rads), the hazard will be low because of the small total volume of tissue exposed at this level. On the basis of the effect necessarily following an acute inflammatory condition, the hazard would be lower than for the second postulate.

In a recent review of radiation carcinogenesis, Furth and Lorenz state that "Skin tumors do not develop following irradiation without an attendant reversible inflammation." They also state that "It is now well established that a single local exposure is likely to cause a neoplasm only under exceptional circumstances . . . . ".

In summary, it is my opinion that the probability of tumor induction in off-site personnel, at least, under present possible conditions of exposure, is so small as to be indistinguishable from zero.

Nevertheless, an animal experimentation program with the specific particles will be started immediately to test the point.

We also pointed out that worry about carcinogenesis could be eliminated by making a small excision of tissue at the site of a demonstrable beta ray burn. Since this simple defensive measure is apparently considered ridiculous, I believe that it puts the risk of cancer production in proper perspective. It would not be ridiculous to identify and mark for annual examination all areas exhibiting severe skin reaction. Since the military personnel on the site appear to be at greatest risk, such a program for them is being encouraged.

 [redacted]

b. Inhalation

The remote possibility of tumor induction in the lung was implied in our reservations on the effects of insoluble particles. This point was raised in our first "particle problem" six years ago. There has been little experimental progress to date on this point. The present particles do not have specific activity as high as those encountered in other problems.

Dr. Bugher confirmed my assumption of motion along the upper respiratory tract, my value being quite conservative. An exception would be the case of an individual with a prior clinical defect in the ciliary process. Obviously the probability of such a person being involved is extremely low.

c. Ingestion

While conceding the qualitative reliability of the Appendix C, Dr. Bugher pointed out that trapping of particles in the G. I. tract is quite common, the mouth of appendages such as the secum or appendix being favored locations. The risk from a large ingested particle is therefore greater than I had implied. A practical probability will be derived by animal experimentation.

With these exceptions, our general conclusions on the hazard were essentially confirmed by the visitors, and their counsel was appreciated. Some of the plans for biological experimentation were discussed in some detail, and helpful criticisms and suggestions were received.

18. Summary

A brief account of the widespread contamination arising from ruthenium emissions in the Redox process is given. Physical nature, radiochemistry and persistence of the offending particles are outlined. Notes on the relevant biological and biophysical experimentation bearing on the problem are given. As a base point, a particle reading 100 mrads per hour on routine survey has anticipated linear dimensions of about 40 microns, contains about 1.1 μc $Ru^{103,106}$ and can give a skin contact dose of about 160,000 rads in 24 hours. It is estimated that this particulate irradiation would be more nearly equivalent to 200-2000 rads (perhaps $\sim$ 300 rads) as conventionally given over a small extended area (a few cm^2). Inhalation and ingestion hazards are also considered; with some reservations these are less likely to be critical under existing conditions of contamination.

It is suggested that the probability of a significant injury to personnel off-site is so low that a demonstrable public health hazard does not exist. On the reservation there appears to be the potential for uncomfortable superficial injury to tissue. No evidence of such injury has been noted.

For convenient reference, the actual and additional feasible defensive measures are mentioned. Information channels to the AEC and the public are discussed. Appendices give some dose calculations in more detail, together with data on density and severity of particle depositions in off-project locations.

[redacted]

Notes written after the consultation with Dr. Bugher are included. The principal change in emphasis is in some concern over development of tumors in irradiated skin areas.

Appendix A

Sample Calculation of Skin Dose from Particle Contact

Consider a particle A of $\frac{Ru^{103}}{Ru^{106}}$ ratio of 0.75 with a survey dose rate of 100 mrads/hr. The activity of such a particle is about 1.1 μc, and its probable diameter 40 microns.

Consider also a similar particle B of survey dose rate 1 rad/hr with activity 11 μc and diameter 120 microns. When particles A and B are in contact with skin, the dose rates in tissue below the particles can be computed by methods developed independently by W. C. Roesch and J. W. Healy. Such methods are internally consistent to a factor of 2 and are probably realistic within a factor of three. The doses quoted below are approximate averages of the two methods.

Depth Below Surface m.m.	Dose-rate rads per hour	
	Particle A	Particle B
0.07	6,600	27,500
0.1	3,300	16,500
0.2	900	5,500
0.5	90	650
1.0	18	150
5.0	0.7	6.5
10.0	0.15	1.5

For skin over the greater part of the body, 0.07 mm is the minimum depth of interest, as this corresponds to the thickness of the horny layer (7 mg/cm^2).* On the palms of the hands and soles of the feet, the minimum thickness of interest is 0.4 to 0.6 mm.

The maximum range of the beta particles in tissue is about 17 mm, but the phenomenon is almost entirely limited to a practical range of 10 mm. Within this range, the gamma-ray component is less than 1% of the beta-ray component and is not included.

*We assume that tissue has specific gravity 1.0. The refinement to the real specific gravity of 1.02 or 1.03 is not justified, due to other uncertainties.

The average energy absorption in hemispheres centered on the particle is of interest, and is approximately as follows:

Radius of Hemisphere mm	Average Energy Absorption rads per hour	
	Particle A	Particle B
0.5	380	3000
1	90	750
2	21	190
3	9	85
4	4.5	44
5	3	26

Throughout the present calculations, it is assumed that survey dose-rates can be translated to activity through the relation

1 μc → 90 mrads per hour survey

Obviously the relation is a function of ruthenium isotopic ratio. Synthetic sources gave these values:[8]

Ru^{103}/Ru^{106} ratio	mrads/hr/μc
3	66
1	83
0.75	87
0.5	93
0	115

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Refinements in calculation to cover this point are not necessary since all computed skin doses may be wrong by a factor of 3. We have chosen a value that weights the results in favor of the more dangerous component Ru^{106}.

Dose in Related Exposure Circumstances

For comparison, we include dose data on two familiar cases:

I. It is common radiotherapeutic practice to insert gold seeds containing 1 mc radon in tissue. The seeds have 0.3 mm gold wall and the emitted radiation is primarily gamma. The activity decays with a half-life of 3.8 days and 75% of the energy is released in the first week.

Dose data are:

Radius mm	Initial Dose-rate rads/hr	Dose in First Week rads	Total Dose rads
0.3	9,100	870,000	1,200,000
0.5	3,300	320,000	440,000
1.0	820	80,000	110,000
5.0	33	3,200	4,400
10.0	8.2	800	1,100

Such gold seeds produce severe local reaction normally including a necrotic area around the seed. Recovery is eventually essentially complete. If we compare this with the radiation pattern of particle B, it would appear that the pattern would be similar to that of a 0.2 mc gold seed; once it is admitted that tissue will die at a radius of about 0.5 mm, the higher dose at actual contact is irrelevant. Therefore one guidepost is that a particle reading 5 rads/hr survey will show damage on the same order as a conventional 1 mc gold seed implantation.

II. P^{32} beta ray exposures with 1 inch diameter disks have been given up to about 1000 rads. The observable results are tanning, prolonged erythema and some desquamation. The skin eventually recovers.

The dose pattern was approximately as follows:

Depth mm	Dose rads	Average Energy Absorption to the Stated Depth (rads)
0.07	~ 1000	-
0.1	910	~ 950
0.2	830	~ 870
0.5	620	~ 800
1.0	390	~ 600
2.0	150	~ 450
3.0	50	~ 350
4.0	13	~ 280

Compared with particle irradiation, the dose in this case falls off much more slowly with depth. This is presumably much more damaging. The significant difference is the large area irradiated. We can allow for this by computing integral doses to given depths.

[redacted]

[redacted]

Integral Dose for Particle A and for P^{32} Disc

Dimension* mm	Particle A ergs/hr	P^{22} Disc ergs	Particle A Hours to Equal Disc
0.5	10	19,500	1950
1.0	18	29,000	1600
2.0	34	42,000	1230
3.0	50	50,000	1000
4.0	60	53,000	900

*The dimension is the radius of a hemisphere for the particle and the slab thickness for the disc, so the data are not quite comparable.

If the essential phenomenon occurs in a dimension of 0.5 to 2.0 mm, about 1500 particle A hours would equal the disc exposure. That is, particle A for 60 days or particle B for 6 days would give about 1000 rads equivalent extended dose. This is not incompatible with the pig skin exposure data.

This line of reasoning adds some credence to the estimates given in Section 10. However, I would expect it possibly to give an underestimate of the particle hazard.

Appendix B

Irradiation of Upper Respiratory Passages

I know of no authentic calculations on this point. This section is included as a target for discussion.

A 20 μ diameter particle is about the upper size limit for deposition in this zone. The relevant contact dose-rate is on the order of 600 rads per hour. The effective range for heavy irradiation is on the order of 1 mm. Cilia sweep the zone at 4 to 6 cycles per second. The probability of a particle remaining within a 1 mm zone for as much as one-half hour appears to be vanishingly small. Therefore total dose is limited to less than 300 rads. Protection will also be provided by the mucous lining which is itself renewed several times per hour.

The risk of multiple exposures of consequence in the same area is negligibly small.

Thus this hazard does not seem to be a limiting one.

[redacted]

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Appendix C

Note on Gut Irradiation

Consider the hottest particle detected this year (20 rads/hr survey) to move uniformly through the gastro-intestinal tract and be maintained in contact with the gut wall. The essential high dose phenomenon is limited to a range of not more than 1 mm. This will be traversed in 1 to 2 seconds. The contact dose-rate is about 150,000 rads per hour.

∴ delivered dose = 40 - 80 rads

It follows that serious trouble in the intestine could develop only from ingestion of an inconceivably large number of particles or from the hold-up in one location for a considerable time; this is not inconceivable but it does not appear probable.

In actual fact, passage through the intestine protected by inert waste material with insignificant exposure to the gut wall should be the normal case. (But see also Section 17)

Appendix D

Density and Severity of Deposition in Public Areas (as of about 9-3-54)

Number of Square Feet that Contain 1 Measured Particle

Richland - general	2,500
Richland - grassy areas	1,100
Pasco-Kennewick	4,000
Benton City to Enterprise	3,300
Benton City to Columbia Camp	2,500
Wahluke Slope	2,000
Mesa (small sample)	600
Connell	7,000
Ringold	5,400
Ringold to Pasco	2,200

Locations Essentially Free from Contamination

Lind, Othello, Colfax, Prosser, Sunnyside, Grandview, and Yakima

Severity Distribution of Off-Site Particles

Dose-Rate Range mrads per hour	Number Detected	Percent Abundance
1 - 5	17	5.9
5 - 50	189	65.6
50 - 100	46	16.0
100 - 200	28	9.7
200 - 300	5	1.7
300 - 400	1	0.4
400 - 500	0	0
(700)	1	(0.35)
(1400)	1	(0.35)
	288	100.0

[redacted]

[redacted]

Search methods should find all particles reading 5 mrads per hour or more, but could miss weaker ones. This may explain apparent low frequency in first dose-rate range.

With the reported distribution, the "average" particle activity is 0.5 μc.

Therefore in grassy areas of Richland, as an example, there will be about 0.5 μc per 1000 sq. ft.

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[redacted]